3.0   Consequences and Likelihood of Pipeline Failures

3.1   Consequences

The consequences of pipeline failure depend on the product being transported, the manner in which the pipe fails, pressure, and location. The major hazards associated with products transported by pipeline are flammability and toxicity. Products such as natural gas and petroleum liquid products are flammable and can result in fire or explosions under certain conditions. Chemicals such as ammonia are toxic above certain airborne concentrations. In general, the larger the pipeline, the higher the pressure and the closer it is to people, the greater the potential severity of the consequences. As noted in the previous section, the Protocol focuses on flammable materials because most of pipelines that the LEAs will encounter are likely to be for this class of products.

This Protocol considers the consequences of product releases in terms of selected impacts of those releases. Several types of fires and explosions are possibilities with the secondary impacts of harm to persons within an impact distance. The Protocol refers to that distance as the distance between the hazard source and the evaluation location. In this Protocol, the hazard source is either a specific point along the segment of pipeline under study, or, in the case of liquid releases, a point some distance away from the pipeline where liquid flowed and pooled before igniting.

Six release "Protocol Basis Scenarios" are defined for the risk analysis in this Protocol. They are combinations of the release mode (leak or rupture), and the results of an ignition:

- Leak jet (or pool) fire;
- Rupture jet (or pool) fire;
- Leak flash fire;
- Rupture flash fire;
- Leak explosion; and
- Rupture explosion.

The physical consequences of a release are estimated by modeling the physical impacts of a release based on the fundamental equations of fluid dynamics and combustion, well established in the technical literature. The equations of dispersion modeling are used to estimate the airborne concentrations of gas or vapor from a release, and fire and explosion modeling is used to estimate the effects of a release that ignites. A number of models have been proposed in the technical literature and have been captured in various computer software programs. All such models are based on variations of the same basic equations but differ in the underlying simplifying assumptions that are required to solve the complex mathematics. This results in different degrees

of both accuracy and precision for given situations. The mathematical model used for consequence estimates in this Protocol is the U.S. Environmental Protection Agency, Areal Locations of Hazardous Atmospheres (ALOHA®) Model, available from the U.S. EPA website (EPA 2006a, 2006b).

The hazard from a jet or pool fire is the thermal radiation that is emitted. Above a certain threshold for given exposure time, people may suffer injury or fatality. The intensity of this heat flux varies with the size of the fire in terms of flame dimensions and other variables. This heat flux decreases with distance from the fire. Therefore, the risk from exposure to a fire decreases with distance. The Protocol uses equations from the technical literature to estimate these effects in calculating the individual risk and potential effects on exposed populations. The severity of these effects depend on the intensity expressed in units of British thermal units per square foot transmission area per unit of time (e.g., per hour) (Btu/ft^2-hr).

A flash fire is a rapid propagation of a flame front through a flammable gas or vapor cloud without a damaging pressure increase, as would occur in a detonation, for which the term explosion is reserved in the Protocol. Persons caught within such a zone of deflagration can suffer injury or fatality. The complexity of the phenomenon makes flame patterns and thermal effects highly uncertain. A fire occurs only if the flammable gas or vapor mixture lies within the concentration range defined as the flammability limits, expressed as the volume percentage of the gas or vapor concentration in air. The lower flammability limit (LFL) defines the lower boundary necessary for combustion, and the upper flammability limit (UFL) the upper boundary. The hazard for a flash fire at a given location depends on whether the LFL reaches that location or lies within a zone bounded by the LFL. Gas and vapor dispersion modeling is used to estimate the distance from the hazard source to estimate the risk from exposure to a flash fire.

Similar considerations apply to explosions. However, gas cloud and vapor cloud explosions are very complex phenomena that require the right combination of gas or vapor concentrations in air, total mass of flammable material, spatial distribution of this material, and some degree of confinement, either because of the cloud itself or from physical barriers in the surroundings. Unconfined gas and vapor cloud explosions are extremely rare because of the combinations of parameters that must be convergent in the right combinations. Various models have been proposed to model such explosions and all are an approximation with a high degree of uncertainty. The hazardous effects of an explosion result primarily from the increase in pressure at a point from a blast or shockwave as it passes through the air. This overpressure is expressed in unit of pound per square inch (psi) above the normal atmospheric pressure. A true explosion is defined as an ignition for which the overpressure is high enough to cause significant damage to

people or structures and is classified as a detonation. Otherwise, the ignition is a flash fire or deflagration. The overpressure decreases with distance from the origin of the explosion.

The risk of injury or fatality depends on the intensity and time of exposure to thermal radiation or overpressure. Various equations are presented in the technical literature for estimating these effects. The exposure component of risk means that there is a difference for persons outdoors compared with indoors when fire or explosion events occur. For fires, there is some protection from being inside buildings when the fire is outside. For explosions, the risk of injury or fatality depends on both the direct effects of overpressure and the threat from debris and structural collapse in buildings. In some situations, outdoor exposure could be less risky than indoor exposure.

More discussion of consequence analysis is presented in Section 4 on the actual risk analysis computations, with additional background information in Volume 2.

3.2   Likelihood

The Protocol estimates the likelihood of a pipeline failure and product release as an absolute, annual probability value for the pipeline segment of concern. The segment of concern is that portion of a pipeline that lies within 1,500 ft of a school campus property line.

The Protocol uses historical, actuarial data for estimating the probability of a pipeline failure and product release. The final probability of impact starts with the accidental release of pipeline product as the initial event for which a probability is obtained from historical data. Probabilities for the individual events leading to this release are not determined individually. The probability of fire, explosion and any resulting fatalities are determined by considering the conditional probabilities of succeeding events leading to fatality of an exposed individual. These conditional probabilities depend on pipeline characteristics, the distance between the individual and the pipeline, and the individual Protocol Basis Scenario being evaluated. Section 4 provides details of the method, with additional background information in Volume 2.

Evaluating the potential for a hazardous material emergency in any given location involves use of historical accident data in conjunction with local conditions (to the extent possible) to predict the likelihood of future accidents, and to some extent, the general consequences of these events (FEMA, 1989). Prediction of the future, of course, is an inexact science, but probabilistic risk assessment methods can provide approximate indications of the number and nature of accidents expected on average in a given locale within a specified period of time, and can therefore provide valuable guideposts for decision-making purposes.

This technique has been used for years outside of the pipeline industry in the context of hazardous material storage, handling and manufacturing facilities (CCPS, 1989). In some countries it is a government regulatory requirement, but is not generally so in the in the U.S. An exception is Santa Barbara County, California, which has established quantitative risk criteria for certain hazardous material facilities, and by so doing, has implicitly established a requirement for this type of assessment (SBC, 1999).